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Bron, Denis  
Mühlefeld 12  
5016 Obererlinsbach  
SUISSE

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Delivery system for pharmaceutical agents

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## Delivery system for pharmaceutical agents

The present invention relates to a delivery system for pharmaceutical agents. Said delivery system  
5 comprises liposomes which comprise in their internal compartment a pharmaceutical agent to be delivered and which have linked to their external surface a cell adhesion molecule or a fragment thereof.

Liposomes have been widely used for the delivery of a variety of material to cells such as e.g. therapeutic drugs and DNA. In order to target the delivery of the encapsulated material to a specific cell type, various liposome modifications have been developed. In one approach adhesive peptides binding the cell surface molecule ICAM-1 (intercellular adhesion molecule-1)  
15 on the target cells were linked to the liposome surface (Jaafari MR, Foldvari M, J. Pharm. Sci. 91(2): 396-404, 2002). In another approach cationic liposomes were targeted *in vitro* to specific tumor cells by means of monoclonal antibodies (Kao GY et al., Cancer Gene Ther. 3(4):  
20 250-6, 1996).

The hitherto know liposome based delivery systems have a major drawback, since they do not allow an efficient delivery of pharmaceutical agents to cells.  
25 There is therefore a need for alternative liposome based delivery systems for pharmaceutical agents.

Hence it is an object of the present invention to provide a system for the intracellular delivery of pharmaceutical agents wherein said system comprises  
30 liposomes which comprise in their internal compartment a pharmaceutical agent and which have linked to their external surface a cell adhesion molecule or a fragment thereof wherein said cell adhesion molecule is selected from the group consisting of ICAM (intercellular cell adhesion molecule), NCAM (neural cell adhesion molecule),  
35 VCAM (vascular cell adhesion molecule), PECAM (platelet-endothelial cell adhesion molecule), ALCAM (activated

leukocyte cell adhesion molecule, LFA (lymphocyte function antigen), selectins, laminin, fibronectin, cadherins. A preferred cell adhesion molecule for the inventive delivery system is NCAM.

5 In a preferred embodiment of the present invention said cell adhesion molecule is linked to said external surface of said liposomes via a transmembrane domain or a hydrophobic anchor molecule which allows the cell adhesion protein to be tethered to the lipid bilayer  
10 such as e.g. a GPI anchor or by isoprenylation of the cell adhesion molecule.

Methods for the production of liposomes are known to the man skilled in the art and e.g. described in *Liposomes a practical approach*. RRC New Editor. IRL press  
15 at oxford university press. 1990.

The term "cell adhesion molecule" as used herein encompasses at least cell adhesion molecules isolated from their natural source, cell adhesion molecules produced by recombinant technology, and cell adhesion  
20 molecules produced by *in vitro* peptide synthesis and fragments thereof.

The term pharmaceutical agent as used herein encompasses all classes of chemical compounds exerting an effect in a biological system. Preferred pharmaceutical  
25 agents for the use in the present invention are molecules selected from the group consisting of DNA, RNA, oligonucleotides, polypeptides, peptides, antineoplastic agents, hormones, vitamins, enzymes, antivirals, antibiotics, antiinflammatories, antiprotazoans, antirheumatics, radio-  
30 active compounds, antibodies, prodrugs, and combinations thereof.

In a preferred embodiment of the present invention said pharmaceutical agent is a DNA, preferably a cDNA which is operably linked to a gene expression construct allowing expression of said cDNA, more preferably  
35 said cDNA encodes a functional protein. Typically, an expression construct comprises the regulatory sequences re-

quired to achieve expression in the host cell and it may contain necessary sequences required for plasmid replication in order to exist in an episomal state, or it may be designed for chromosomal integration. The term regulatory  
5 sequence as used herein encompasses both the native regulatory sequence of the gene to be expressed from said expression construct and heterologous regulatory sequences. The construction of such expression constructs are known to the man skilled in the art and are e.g. described in  
10 *Sambrook et al., Molecular Cloning: A Laboratory Manual, New York: Cold Spring Harbor Laboratory, 2001.*

When said expression construct is intended for chromosomal integration, the integration into the host genome is preferably achieved by including cis-  
15 elements into the expression construct that can be recognized by a transiently expressed transposase such as e.g. Sleeping Beauty. The transposase can be expressed temporarily by including the cognate mRNA into the delivery system. Said expression construct intended for chromosomal  
20 integration preferably comprises cis-elements preventing transcriptional silencing that follows random integration.

In another preferred embodiment said construct further comprises locus control elements (LCR)  
25 e.g. matrix attachment sites.

In a much preferred embodiment of the present invention said DNA encodes the human dystrophin protein.

In a preferred embodiment of the invention said delivery system comprising as pharmaceutical agent a  
30 DNA further comprises a DNA compacting agent such as e.g. cationic peptides. Said DNA compacting agents reduce the size of the liposome particles. Preferred DNA compacting agents are reversibly cross-linkable cations that can be crosslinked after particle formation. A much preferred  
35 crosslink is a thio bridge.

In another preferred embodiment of the invention said delivery system comprising as pharmaceutical

agent a DNA further comprises a chemical inclusion such as e.g. secondary and tertiary amines and/or a biological inclusion such as e.g. adeno fiber, to breach the intracellular endosomal barrier.

5           Said delivery system comprising as pharmaceutical agent a DNA preferably comprises nuclear localisation signals, more preferably said nuclear localisation signals are PNA linked peptides and/or PNA linked ligands. Said PNA linked peptides or PNA linked ligands can  
10 be picked up by nuclear-cytoplasmic shuttles and lead to the nuclear delivery of the DNA.

          In another preferred embodiment of the invention said delivery system comprising as pharmaceutical agent a DNA further comprises an anti-apoptotic activity.  
15 Preferred anti-apoptotic activities are selected from the group consisting of a mRNA encoding Bcl-2, a small interfering RNA (siRNA) directed against Bax and a peptid comprising caspase inhibitor sequences. The inventive delivery system can comprise one of said anti-apoptotic activities or a mixture thereof. Said activities are included into the inventive delivery system in order to  
20 avoid that successfully transfected cells are lost due to apoptosis.

          It has to be understood that the inventive  
25 delivery system for DNA can comprise any combination of the structural elements disclosed in the above embodiments.

          Another object of the present invention is a pharmaceutical composition comprising a delivery system  
30 according to the present invention.

          The delivery system and the pharmaceutical composition of the present invention are suitable tools for the treatment of various human diseases such as e.g. genetic diseases and cancer as well as for gene therapy.  
35 The inventive delivery system comprising as pharmaceutical agent a DNA encoding a functional dystrophin protein is a useful tool for the treatment of Duchenne muscular

dystrophy. Depending on the cell adhesion molecule included in the inventive delivery system a pharmaceutical agent can be targeted to specific cells and/or tissue in the human or animal body. The delivery system of the present invention can as well be used for the introduction of pharmaceutical agents into cells *in vitro*.

The inventive delivery system or pharmaceutical composition can be administered intravenously as a bolus or by continuous infusion over a period of time, by intramuscular, subcutaneous, intra-articular, intrasynovial, intrathecal, oral, topical, or inhalation routes. Such pharmaceutical compositions can encompass pharmaceutically acceptable carriers that are inherently nontoxic and nontherapeutic. Examples of such carriers include ion exchangers, alumina, aluminum stearate, lecithin, serum proteins, such as human serum albumin, buffers such as phosphate or glycine, sorbic acid, potassium sorbate, partial glyceride mixtures of saturated vegetable fatty acids, water, salts, or electrolytes such as protamine sulfate, sodium chloride, metal salts, colloidal silica, magnesium trisilicate, polyvinyl pyrrolidone, cellulosic polymers, and polyethylene glycol.

The invention is now further illustrated by means of examples.

Example 1: Production of liposomes having incorporated into their membrane cell adhesion molecules

Dry 0.5  $\mu\text{mol}$  of dioleoyl phosphatidyl choline under nitrogen in a disposable glass tube. Evacuate in dessicator under vacuum for 30 minutes. Add buffer/dH<sub>2</sub>O to required volume and scrape the sides of the glass tube to dislodge the lipid. Add protein a 1 $\mu\text{g}/\mu\text{l}$  of lipid used. Vortex for 30 seconds. Sonicate twice in a bath sonicator at 7 degree for 15 seconds.

This procedure results in multilamellar vesicles that become small unilamellar vesicles (SUV) with

prolonged sonication time. To make large unilamellar vesicles, use the extruder.

5     Example 2: Expression of lipid tagged proteins and preparation of liposomes having incorporated said lipid tagged proteins.

      E. coli strain HB101 was transformed with a plasmid and cultured in LB medium with ampicillin at 37°C.  
10    The plasmid encodes a hexahistidiny tail for purification of the tagged protein. The DNA sequence encoding the signal peptide and the N-terminal amino acid residues of the major lipoprotein of E. coli (lpp) was linked to the DNA encoding the protein. The N-terminal cysteine residue of  
15    the resulting protein is enzymatically linked with the lipids in the bacterial membrane. After induction with IPTG, the cells were cultured another 12 h at 30°C and harvested by centrifugation. The cells from 1 l culture were suspended in 50 ml lysis buffer and lysed by sonica-  
20    tion. The cell envelopes were collected by ultracentrifugation (150'000 g, 1h, 4°C), the pellet was suspended in HEPES buffer (pH 7.4) containing 1% (w/v) Triton-X-100. The sample was applied to a Ni<sup>2+</sup> column to purify the lipid tagged proteins having a hexahistidiny tail.

25       Ten milligrams of phosphatidylcholine was dissolved in 1 ml of chloroform in a test tube. After drying well under a stream of nitrogen, it was suspended in 1 ml HEPES buffer solution (pH 7.4) and sonicated for 10 min. After centrifugation at 30'000 g for 20 min, the  
30    final pellet of liposomes was suspended in 1 ml of HEPES buffer. Then the solution of purified lipid tagged proteins were added to the resulting liposomes with stirring at 4°C.

Claims

1. A delivery system for pharmaceutical agents wherein said system comprises liposomes which comprise in their internal compartment a pharmaceutical agent and which have linked to their external surface a cell adhesion molecule or a fragment thereof wherein said cell adhesion molecule is selected from the group consisting of NCAM, ICAM, VCAM, PECAM, ALCAM, LFA, selectins, laminin, fibronectin and cadherins.
2. The delivery system according to claim 1, wherein said cell adhesion molecule is NCAM.
3. The delivery system according to claim 1 or 2, wherein said cell adhesion molecule is linked to said external surface of said liposomes via a transmembrane domain or a hydrophobic anchor molecule.
4. The delivery system according to anyone of the preceding claims, wherein said pharmaceutical agent is selected from the group consisting of DNA, RNA, oligonucleotides, polypeptides, peptides, antineoplastic agents, hormones, vitamins, enzymes, antivirals, antibiotics, antiinflammatories, antiprotozoans, antirheumatics, radioactive compounds, antibodies, prodrugs, and combinations thereof.
5. The delivery system according to claim 4, wherein said pharmaceutical agent is a DNA, preferably a cDNA which is operably linked to a gene expression construct.
6. The delivery system according to claim 5, wherein said cDNA encodes a functional protein.
7. The delivery system according to claim 6, wherein said functional protein is the human dystrophin protein.
8. The delivery system according to anyone of claims 5 to 7, wherein said delivery system comprises a DNA compacting agent.

9. The delivery system according to claim 8, wherein said DNA compacting agent is a reversibly cross-linkable cation.

10. The delivery system according to claim 9,  
5 wherein said reversible cross-link is a thio bridge.

11. The delivery system according to anyone of claims 5-10, wherein said delivery system comprises a chemical inclusion and/or a biological inclusion for the breaching of the endosomal barrier.

10 12. The delivery system according to anyone of claims 5-11, wherein said delivery system comprises a nuclear localisation signal, preferably in the form of PNA linked peptides or PNA linked ligands.

15 13. The delivery system according to anyone of claims 5-12, wherein said delivery system comprises an anti-apoptotic activity.

14. The delivery system according to claim 13, wherein said anti-apoptotic activity is selected from the group consisting of a mRNA encoding Bcl-2, a small  
20 interfering RNA directed against Bax, a peptide comprising caspase inhibitor sequences.

15. A pharmaceutical composition comprising a delivery system according to claims 1 to 14.

Abstract

The present invention relates to a delivery system for pharmaceutical agents. Said delivery system  
5 comprises liposomes which comprise in their internal compartment the pharmaceutical agent to be delivered and which have linked to their external surface a cell adhesion molecule or a fragment thereof wherein said cell adhesion molecule is selected from the group consisting of  
10 of ICAM (intercellular cell adhesion molecule), NCAM (neural cell adhesion molecule), VCAM (vascular cell adhesion molecule), PECAM (platelet-endothelial cell adhesion molecule), ALCAM (activated leukocyte cell adhesion molecule). A preferred cell adhesion molecule is NCAM. In  
15 a preferred embodiment said pharmaceutical agent is a DNA, preferably a cDNA which is operably linked to a gene expression construct.